

Citation for published version:

Fodde, E 2008, 'The influence of soluble salts on the decay of Moenjodaro, Pakistan', *Structural Survey*, vol. 26, no. 3, pp. 223-241. <https://doi.org/10.1108/02630800810887117>

DOI:

[10.1108/02630800810887117](https://doi.org/10.1108/02630800810887117)

Publication date:

2008

Document Version

Peer reviewed version

[Link to publication](#)

This article is © Emerald Group Publishing and permission has been granted for this version to appear here <http://opus.bath.ac.uk/>. Emerald does not grant permission for this article to be further copied/distributed or hosted elsewhere without the express permission from Emerald Group Publishing Limited.

University of Bath

Alternative formats

If you require this document in an alternative format, please contact:
openaccess@bath.ac.uk

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

THE INFLUENCE OF SOLUBLE SALTS ON THE DECAY OF MOENJODARO, PAKISTAN

Enrico Fodde

BRE Centre for Innovative Construction Materials,
Department of Architecture and Civil Engineering
University of Bath
Bath BA2 7AY, UK

Tel: +44 (0) 1225 383185
Fax: +44 (0) 1225 386691
Email: E.Fodde@bath.ac.uk

Enrico Fodde (MA, PhD) is Lecturer at the BRE Centre for Innovative Construction Materials, Department of Architecture and Civil Engineering, University of Bath (UK). He was formerly international project director of Moenjodaro (World Heritage site, Pakistan), consultant to the Abu Dhabi Authority for Culture and Heritage (UAE), and field director of the following UNESCO projects: conservation of the Buddhist monastery of Ajina Tepa (Tajikistan), the Silk Road sites of the Chuy Valley in Kyrgyzstan (Krasnaya Rechka, Ak Beshim, Burana), and Otrar Tobe (Kazakhstan).

Abstract

Purpose The World Heritage site of Moenjodaro, located in the Indus flood plain and dating to the early Bronze Age, is believed to be the most important urban centre of the Indus valley culture. The purpose of the paper is to discuss the main conservation threats and the mechanisms of decay affecting the site and to understand the influence of soluble salts on materials such as fired brick and soil. Furthermore, the paper describes the repair methods employed against salts attack and provides a scheme for site management.

Design/Methodology/Approach Laboratory analysis, literature review

Findings The main result is the experimental assessment of repair materials traditionally employed in Moenjodaro. No evaluation was undertaken prior to this study and this makes the work the more relevant.

Research limitations/implications A more complete and detailed study of the materials examined here might have been achieved if more samples had been analysed. The present study is therefore characterised by this limitation which however does not undermine the significance of the work.

Practical implications The results have practical applicability to the conservation of Moenjodaro in a variety of ways. The experimental analysis of materials will be essential to determine the type of intervention required for conserving the site.

Originality/Value The value of this paper derives from the originality of the work done, being the first of its kind for Moenjodaro. It will be especially useful to those conservators working in the site, but also in similar sites. It stresses on the importance of testing before any conservation work is carried out.

Keywords Fired brick, mud mortar, sodium sulphate, conservation measures, archaeology

Paper type Research paper

HISTORY OF THE SITE

The site, located 32 km south of Larkana in the province of Sindh, was the epicentre of the Indus valley civilization (Plates 1-4). It was discovered in 1922, but the major excavation was carried out between 1924 and 1933 by the Archaeological Survey of British India under John Marshall¹. Ernest Mackay carried out excavations until 1936, and other archaeologists followed². It was calculated that the 100 excavated hectares amount to about 10% of the total extent of buried Moenjodaro (Shaikh and Ashfaq 1981, 39).

The site is believed to have flourished from 2350 to 1800 BC, but it comprises later features such as the Buddhist monastery (II century AD) that include a stupa made of fired brick and mud brick³. The importance of Moenjodaro lays in its urban structure, being the most ancient known form of planned city in the world. The excavated areas reveal dense patterns of residential buildings and narrow alleys, whilst areas such as DK-G show examples of more affluent dwellings⁴. The wealth of the city is indicated by the administrative centre that includes impressive architectural features such as the great bath, the granary, and the pillared hall. Other important features of Moenjodaro are the wells and the sophisticated sewage and drain system to discharge water away from the city. The site is built with mud brick (10x20x40 cm), employed mainly for the erection of enormous platforms on which the city was founded⁵, and fired brick (6.3x13.4x27.9 cm) for the construction of dwellings⁶.

Take in Plate (No. 1)

Take in Plate (No. 2)

Take in Plate (No. 3)

Take in Plate (No. 4)

In 1972 a master plan for the conservation of the site was prepared jointly by the Government of Pakistan and UNESCO. The key points of such plan were: river training, ground water control, conservation of structural remains, plantation of salt tolerant vegetation, landscaping, and cultural tourism. The first three points of the master plan were implemented between 1979 and 1997 with the following activities: construction of five spurs and armoring of the right bank of the Indus to stop the tendency of the river to flow towards the site, setting up of 27 tube wells, establishing 39 piezometres for the monitoring of ground water table, construction of a circular collector drain around the site, construction of pumping station and disposal chain, and conservation work. Plantation, landscaping, and cultural tourism were not implemented and are still today neglected.

In the early 1980s the Water and Soil Investigation Laboratory (WASIL) was established in the Moenjodaro campus by the Department of Archaeology and Museums with the support of UNESCO⁷. The aim of the WASIL is to carry out analysis of conservation material, water, soil, and to collect feedback data on conservation measures. In the beginning the laboratory was employed only for the analysis of water and soil samples. Later on the functions expanded, collecting various types of analytical information: environmental data (relative humidity, rainfall, temperature), detailed analysis of water (conductivity, pH, total dissolved salts), soil analysis (sieving, plastic limit, liquid limit, shrinkage, soluble salts), water table monitoring with piezometres, soil moisture content, moisture content of walls, monitoring of conservation measures (moisture content and relative humidity of important structures such as the stupa), analysis of conservation material (fired brick, mud mortar, and mud brick), and collection of feedback data on conservation measures.

In 2005 the Moenjodaro Conservation and Research Centre (MCRC) was established as a management structure of the site. This was dismantled after one year and at present the organization responsible for the conservation of the site is the Department of Archaeology and Museums (Ministry of Culture, Sports, and Youth Affairs).

MECHANISMS OF DECAY

The main causes of decay of Moenjodaro are: soluble salts attack in conjunction with rising damp and collection of dew, heavy precipitation (concentrated especially in the monsoon season), thermal stress causing walls to lean and decay structurally, poor drainage, and man-made damage.

Soluble salts attack

In the cool season lower brick courses show a thick layer of salts efflorescence up to 1-1.5m (Plate 5). The process through which the phenomenon occurs was explained by Boekwijt (1979, 6): 'The bricks of the remains have a high salt content estimated per brick at about 20gr sodium chloride, 20gr sodium sulphate, and a minor amount of carbonates and bicarbonates of calcium, sodium and magnesium.' And again (Various Authors 1987-1988, 4): 'Excavated brick structures at Moenjodaro are deteriorating at an unacceptable high rate because of crystallization and hydration of the mineral thenardite (sodium sulphate). Its destructive effect is mainly attributed to a volume increase of 315 percent resulting when

thenardite hydrates to form mirabilite (sodium sulphate decahydrate). Subflorescence of soluble salts is a much more destructive process than efflorescence.' The reaction through which this occurs, at the equilibrium temperature of 32.5 degrees C, is $\text{Na}_2\text{SO}_4 + 10 \text{H}_2\text{O} \rightarrow \text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$. Thenardite collects the water molecules either from rising damp or from atmospheric moisture (dew). Originally it was felt that the decay of structures was to be attributed to the rising of ground water table consequent to the construction of a neighbouring network of irrigation canals. Hence the setting up of piezometres, the construction of a pumping station and collector drain around the site. However, recent investigation showed that ground water table is not the only parameter influencing the decay of structures, the other one being hygroscopic collection of dew by soluble salts.

Take in Plate (No. 5)

Heavy precipitation

Rain tends to concentrate from December to January, but also in June when heavy monsoon can cause major distress especially in terms of drainage. Structures are washed out by precipitation and in this sense mud brick capping plays a relevant role to avoid water infiltration. Mud brick is replaced when heavily eroded, otherwise loose soil is employed for smaller repair or patching. Washing out of mud mortar is another consequence of heavy precipitation, and it is not unusual to observe joints with erosion depth of up to 15 cm. For this reason repointing should not be considered as a cosmetic treatment of walls, but rather as a structural consolidation process.

Thermal stress

Direct inspection revealed that for the majority of cases leaning walls are inclined towards south. This may be attributed to thermal stresses that affect the structures in the hot season, when the exposed wall surface can easily reach a temperature of up to 60 degrees C. If this is compared to the temperature of the portion in shade, it seems likely that the lean is a consequence of this disparity and to one-sided expansion and contraction cycles. However, this conjecture needs to be proved by proper monitoring and experimental analysis.

Lack of drainage

In a site like Moenjodaro, with its meander of alleys and dwellings, the study of drainage is of prime importance for its preservation. The decay mechanisms of the drainage system can be classified as follows:

- i. Wrong employment of recycled soil for the leveling and creation of slopes. There is a clear difference in terms of drainage between the sweet soil that was imported from the Indus river and the local Moenjodaro salty soil;
- ii. Lack of soil compaction is the main deteriorating factor, with consequential creation of underground gullies that divert water towards softer areas. Ramming of soil should be carried out uniformly in order to either divert water from the area, or to create shallow ponding;
- iii. When water is allowed to flow too fast, it creates gullies and water marks in the collection drains. This can also affect walls structurally as water often finds its way below foundation level;

- iv. The employment of concrete or ceramic pipes, a practice that was carried out until recently in Moenjodaro, is not acceptable in terms of conservation philosophy. This type of work would have serious implications because of the destruction of historic fabric before their insertion, but also because water runs in such a way that the historic fabric underneath is washed off.

It is suggested that research and experimentation on drainage be carried out following what advised by Hughes (1995, A4) so that to guarantee proper drainage solutions for the site. Structures do not show major damage at middle level but in some cases decay occurs due to high humidity levels. The protective mud brick capping can wash up to various extents. The weight of the wall increases due to high humidity and salts efflorescence start appearing after evaporation.

Man made damage

An impressive percentage of wall footings were damaged by wrong conservation measures carried out until 2001 (Fodde 2007). This type of intervention is illustrated by Shaikh and Ashfaque (1981, 55) who explain that 'in order to protect the structures from the capillary action that draws water and salts, it is essential to provide damp-proof courses. This will be done with precast concrete slabs of suitable size coated with bitumen on the unexposed surfaces, which are inserted into the masonry. The joints will be filled with bitumen under pressure. The exposed surfaces of the concrete members will be treated with pulverized brick and provided with artificial vertical joints. This method has been tried in the past and has proved quite useful.'

Uncontrolled activity can be a major threat to the site, especially during Eid day festivity when a peak of 65,000 visitors was recorded. However, being the number of visitors per year of 300,000 in average, it is clear that man made damage is not only a problem of single events.

EXPERIMENTAL ANALYSIS

The aim of this section is to study the influence of soluble salts on the decay of Moenjodaro's structures. Two salts-free soil types are traditionally employed in the conservation of the site: silty soil⁸ (for wall capping and shallow ponding) and clayey soil⁹ (for drainage, slurring, and masonry work). The silty soil has the following grain size distribution: gravel 0%, sand 40%, silt 38.3% and clay 21.7%, Munsell colour grayish brown 5/2 10YR. The grain size distribution of the clayey soil is: gravel 0%, sand 7%, silt 42.9%, and clay 50.1%, Munsell colour pale brown 6/3 10YR. The following experimental analysis was carried out in order to assess the extent to which environmental salts cause decay of both soil and fired brick.

Influence of increasing salinity on the moisture content of soil

In order to have a suitable amount of salt for experimenting, this was collected from DK-G south area and put into a beaker with distilled water, agitated, and then left to rest until achieving complete sedimentation. After drying in the oven, the resulting salt was put aside and this process was repeated several times until obtaining a proper amount for experimenting. One sample of clayey soil and one of silty soil were mixed with increasing amounts of such environmental salt so that to provide representative and realistic data (Table 1, see second column). Samples were then left to dry at room temperature for seven

days and weighed. In order to calculate the moisture content, samples were then dried in the oven at 105 degrees C until no weight change occurred. The third column on Table 1 shows the influence of increasing salinity on the moisture content of clayey soil and silty soil, and hygroscopicity of salts. This is an important finding as it demonstrates that rising damp is not the only cause for salts crystallization and the transformation from thenardite to mirabilite. It shows that hygroscopic absorption of moisture from the air can also play a relevant role.

Soil type	Salts content	Moisture (%)	Liquid limit	Plastic limit
Clayey	+0% salts	1.0	35.9	28.4
	+5% salts	3.7	33.3	25.8
	+10% salts	9.8	33.1	24.5
	+20% salts	11.4	29.7	22.4
Silty	+0% salts	0.9	27.6	21.8
	+5% salts	3.0	25.3	21.9
	+10% salts	8.6	25.1	23.3
	+20% salts	12.7	21.8	17.0

Table 1. Influence of soluble salts on key soil parameters such as moisture content, liquid and plastic limit

The influence of soluble salts on the liquid and plastic limit of soil

The aim of this experiment is to study the effect of increasing concentrations of environmental salts on key soil parameters such as the Atterberg limits (the methods employed for the calculation of the Atterberg limits is provided by Teutonico 1985). Two types of salts-free soil were considered for the experiment: clayey and silty soil. Experiments for the measurement of the plastic and liquid limit were carried out by amending such samples with increasing content of environmental salts: 5, 10, and 20%. The fourth and fifth column on Table 1 provide an explanation of the influence of salts content on the Atterberg limits. The main finding after this experiment is that both plastic and liquid limit are inversely proportional to the soluble salts content. Such property is related also to the anticoagulating or dispersing properties of Sodium sulphate when added to clay in solution form. This proves that the higher the salts concentration, the easier it becomes plastic and liquid, with considerable and direct consequences on durability and behaviour of earthen materials, especially when subjected to heavy load. Such result has direct application to the collection of water at foundation level, and to the settling of walls (i.e. leaning walls).

Influence of increasing environmental salts on the durability of earthen materials

Preparation of the soil cubes

Soil cubes were manufactured in order to test their behaviour against capillarity rise and wetting/drying. These were cast from a wooden mould measuring 5x5x5cm. Four cubes were made for both clayey and silty soil with increasing concentration of environmental salts (by weight): 0, 5, 10, and 20%.

Because different soils show different workability when mixed with the same amount of

water, and because different samples show different optimum water contents for maximum performance (also influenced by salts concentration), the mix for moulding the specimens was carried out by adding the amount of water necessary to reach a state between the plastic limit and the liquid limit of every soil sample. Some samples attained their workability when reaching the plastic limit, whilst some other needed more water. As a consequence of this, soil workability was defined as the level of water that allows the mix to be packed in the corners and edges of the mould with the help of a spatula. After the soil was worked into the edges and corners, the mould was filled in with more material and the top surface was smoothed. The specimens were then put to dry at room temperature on evaporating dishes, and turned to their sides after one day. Weighing was carried out daily until specimens do not show any weight change.

Wetting and drying

The scope of this test is the determination of the behaviour of soil prisms when subjected to wetting and drying cycles. The experimental design is a more aggressive simulation than the naturally-occurring causes of weathering of structures. In this respect, this type of test is not a precise repetition of the field conditions where the process occurs more slowly. In order to facilitate manipulation, samples were positioned horizontally onto a tray. Then they were totally immersed in ambient-temperature distilled water for thirty minutes, after which they were dried for in the oven at 100 degrees C until no weight change occurred. After drying, samples were removed from the tray and weighed. Comments on their decay conditions were recorded after completing one cycle of the test. For these samples the problem was at first what to consider as prism and what to consider as loss material, so it was kept as a prism the material included in the 5x5cm perimeter. The weight loss of the soil prism was then calculated. The test was interrupted after the third cycle. As this is such an aggressive test, further repetition could have caused further and unquantifiable disintegration of the samples. The result after the test (Table 2) is that the general tendency for both clayey and silty soil is to decrease the decay due to wetting and drying when the salts content increases. The significance of this result in the context of Moenjodaro is that both soil types have beneficial properties when employed in conservation.

Soil type	Salts content	Wetting and drying. Weight loss (%)
Clayey	+0% salts	10.4
	+5% salts	8.8
	+10% salts	3.6
	+20% salts	6.8
Silty	+0% salts	8.2
	+5% salts	5.3
	+10% salts	11.7
	+20% salts	4.3

Table 2. Influence of increasing salinity on the wetting and drying of soil cubes measuring 5x5x5 cm (3 minutes of immersion)

The influence of increasing environmental salts on the durability of fired brick

The aim of this test is to compare the durability of repair fired brick. Three cubes of dimensions 5x5x5cm were cut from both historic and repair bricks. Cubes were put to soak in distilled water for one week, and water was replaced daily to clean samples from soluble salts. Drying of cubes was carried out in the oven at 105 degrees C. Soaking and drying were repeated until no weight change occurred. A 14% solution of environmental salts and distilled water was then prepared and cubes were soaked in the solution for 24 hours and then dried in the oven at 60 degrees C for 24 hours. After weighing, cubes were immersed again in the solution. These cycles were repeated three times. The average increase in weight after three cycles for the historic brick was of 4.4%, whilst that of the new brick was of 12.8%. The main outcome after the test is that the repair material (new brick) shows a tendency to soak up salt solution faster than the historic brick. This has direct consequences on brick durability (higher salts crystallization of repair brick than historic brick) and confirms sacrificiality of repair interventions.

Monitoring of relationship between salts migration and type of ground surface

The aim of this experiment is to understand the influence of the paving system on the rate of efflorescence of salts. Maintenance of sloping, leveling, and drainage is carried out regularly in Moenjodaro. Removal of saline earth is seldom followed by replacement with mud brick on edge, but more often with loose salts-free soil. Four square ditches measuring 1x1x0.2m were excavated in the saline area adjacent the PD Office, Moenjodaro. These were then filled with the following types of paving: mud brick, mud mortar, rammed earth, and a combined paving made of one layer of sand and one of rammed earth. The four areas were monitored after three months by collecting samples and analysing the total dissolved salts and moisture both on the surface and at a depth of 10cm. Table 3 shows the conductivity measurement and it clearly demonstrates that the paving made of mud brick is the best performing one in terms of salts efflorescence.

Depth	Mud brick on edge	Mud mortar	Rammed earth	Sand and rammed earth
Conductivity ($\mu\text{s}/\text{cm}$)				
Surface	507	2950	Reading over Equipment range	10940
10 cm	611	5530	5840	3160
Moisture (%)				
Surface	1.4	2.8	11.3	2.4
10 cm	2.8	14.0	18.2	3.3

Table 3. Conductivity and moisture content of four types of paving

THE CONSERVATION INTERVENTION

Treatment of wall structures

Basal erosion due to combined action of rising damp and soluble salts is accelerated in the structures that are not protected with mud brick on edge. Not all wall bases in serious state of decay are treated with such method and it is felt that this would be excellent to contain erosion at lower level. Prior to this, the structural condition of single brick should be checked and repointing or resetting should follow. Such treatment should be carried out together with the application of a thick plaster to the wall base up to a height to be defined from case to case (according to the rising damp level). It was in fact noticed that the thickness of the mud slurry is sometimes not adequate to contain the deterioration.

At middle level the application of the mud slurry is advised only after the structural condition of single brick is checked (Plate 6). If necessary, repointing or resetting with new mortar should be carried out as first consolidation measure. At upper level it is suggested that structures be coated with mud slurry application, whilst the top be capped with two mud brick courses.

Heavily affected structures are cleaned from salts attack with mud poulticing (Plates 7-8). This is carried out in several steps: brushing of wall portion and disposal of salts, wetting, application of mud slurry, immediate application of thick mud plaster, packing in order to make sure that the plaster adheres to the wall, waiting until plaster is semi dry, removal of plaster, and brushing of hydrated salts and disposal. The process is repeated several times until complete cleaning of the affected portion.

Take in Plate (No. 6)

Take in Plate (No. 7)

Take in Plate (No. 8)

Winter preparation work

Preparation work for the winter is carried out between October and November in the form

of capping and mud slurring. The methods employed for slurring include: brushing of powdered salts from wall surfaces, collection of brushed salts and disposal away from the site, application of mud slurry to the entire wall, application of second coat of slurry to the wall bases so that to provide an extra sacrificial protection where salts attack is higher. Walls are slurried preferably when in shadow so that to allow proper adhesion of mud slurry to the surface. Only in some cases (i.e. south elevations) slurry is applied when the wall is in the sun and this is done preferably in the early morning.

This preparatory work is essential against salts attack as crystallization occurs predominantly in the winter. The outcome of salts efflorescence is the formation of debris at the wall base. This is formed by decayed mortar, but also by brickwork flaking off. Direct inspection revealed that the latter may be accelerated by wrong conservation measures undertaken in the past. It may be possible that before applying the mud slurry brick surfaces were not properly cleaned with soft brushes and therefore salt crystallization occurs between brick face and mud slurry.

Monsoon preparation work

The monsoon season falls between June and September. Preparation work concentrates mainly on drainage improvement by reinforcing gullies, treating drains, and protecting wall bases). Wall capping is maintained or provided where lacking so that to improve the structural stability of structures, prevent water penetration and collapse. Repointing and grouting is also provided to the most endangered structures (Plate 9).

It is proposed here that topographic remodeling to control surface water flow and ponding is essential for proper drainage. This should be provided by employing the following method (Plate 10): drainage survey and plan to be undertaken with total station before and after any intervention is carried out, scraping and disposal of 10-20 cm of salty soil, creation of slopes by importing sweet soil, laying of a bed of mud bricks (paving system) so that to channel water towards the centre of the area or of corridors, and finally it is advised that no sand bed is applied between the ground and the mud brick so that to allow proper crystallization of salts on the mud brick surface. Leaning walls to be consolidate with fired brick buttresses following what explained in Plate 11.

Take in Plate (No. 9)

Take in Plate (No. 10)

Take in Plate (No. 11)

Monitoring

At present only the stupa is monitored (see Figure 1), but it is suggested here that structures of individual significance are examined in terms of moisture and soluble salts content following this simple method: drilling of inspection holes in the joints (5cm depth and max 1cm diameter), collection of samples in air-tight plastic bags, inserting new cotton (use same type) in the holes and compacting, sealing with tape and plastering with mud, laboratory analysis of moisture and soluble salts content to be repeated monthly. The scope of such experimental monitoring programme is to understand the flow of water in the structure and to use the data as a basis for future conservation. It is very clear from simple visual analysis that water patches are affecting the structures at lower level and that proper conservation measures should be taken to minimize decay. A quantification of humidity

levels in relation to salts content is therefore necessary throughout the year.

Take in Figure (No. 1)

RECOMMENDATIONS AND SUGGESTED ACTIVITIES FOR WIDER MANAGEMENT

Site management

In the area north-east of DK-G villagers regularly drive their vehicles on the archaeology. Direct inspection showed that during Eid day motorcycles are driven between the structures causing damage to the drainage system. Furthermore, uncontrolled visitors access should be stopped and in this sense site fencing is of prime necessity.

The problem of encroachment should be stopped soon. For instance, the neighbouring village of the tribes Behan and Mullah (south area) is only 15 years old and this shows the importance of having a buffer zone and the demarcation of the site boundaries. It is suggested that a plan be provided by the Land Revenue Department and the District Coordination Officer so as to include the areas in the buffer zone.

The documentation centre

One of the most urgent needs for the management of Monejodaro is the proper storage of documentation material such as photographs, drawings, reports, and any other written source. It is suggested that a dust-free office be adapted as documentation centre so that to guest: fire proof steel cabinets for filing of damage assessment and intervention records, fire proof steel cabinets for filing maps, shelves for the storage reports and literature, albums for storing of analogue photographs and negative films. In order to carry out documentation according to the international standards it is necessary to update computers and printers, and to train staff.

Plantation scheme

The objectives of plantation are to provide the site with a barrier against wind blown salts, to reduce ground erosion and soil salinity, and to guarantee shaded areas for visitors. The present state of the excavated areas is that of a barren landscape with little vegetation. In 2005, in order to start the plantation process, a flora survey was carried out to a 500m radius from the circular drain¹⁰. A rough estimate showed that more than 100000 plants are needed to cover the area inside the circular drain. It is suggested that before the final plantation scheme is put into place, the following points be considered:

- i. A testing area (possibly that between SD and HR) to be selected a basis for the plantation scheme. Species to be selected by using the following criteria: only autochthonous species to be allowed in the site, to require minimum amount of irrigation, to use salts as part of their food process, and to have shallow rooting system. Local grass and shrubs should also be included because they act as soil binder against erosion.
- ii. Preparation work is necessary for testing the soil in the laboratory, monitoring of water table, digging of pits, filling of pits with a mix of sweet soil and farm manure, irrigating, and finally planting. The laboratory assessment of soil is necessary because if for instance salts have a high chloride content, plants would not be able

to leach out the salts, and therefore the soil would need to be spread with gypsum to neutralize the salts.

- iii. Monitoring regime for the testing area should include the study of population growth (how many plants survive for every species), growth rate in relation to meteorological data, growth rate in relation to irrigation, salts content of soil and its eventual decrease in relation to vegetation, growth diameter, height, and canopy of trees.

Following the outcome of the experimental plantation, a scheme for the entire site should be proposed, including the selection of autochthonous species and their relationship to the type of soil, and to advise on plantation periods for species and on their water requirement.

Organization of training workshops

The establishment of training courses and workshops is traditional in Moenjodaro and the most recent one took place between 13 and 27 March 2005. It included an historical survey of the site with an in-depth consideration of conservation techniques - in particular historic and archaeological research, documentation as found, damage assessment report, treatment plan, treatment and documentation, and monitoring as a turning point for good practice. The workshop also provided training on laboratory analysis as a fundamental part of the conservation process. Trainees had a hands-on experience on the assessment of historic and new materials for their application within an ethical conservation process. This was combined with two study tours visiting Kot Diji and Sehwan where participants were able to compare conservation issues. The programme for the practical sessions was designed to rotate the following subjects: documentation, conservation, laboratory, and archaeology¹¹.

REFERENCES

Boekwijt, W.O. (1979), *A Critical Review of the Brick Conservation Programme at Moenjodaro*, Restricted Technical Report, UNESCO, Paris.

Briscoe, F. (1997), *Manual for the Conservation and Maintenance of Moenjodaro*, unpublished document, UNESCO, Paris

Bussagli, M. (1981), *Oriental Architecture: India, Indonesia, Indochina*, Electa-Rizzoli, New York

Cooper I. and Dawson B. (1998), *Traditional Buildings of India*, Thames and Hudson, London

De Mario G., Caneva G., Dinelli A. (1990), "Geobotanical foundations for a protection project in the Moenjodaro archaeological area", *Prospezioni Archeologiche Quaderni*, vol 1

Fodde, E. (2007), "Fired Brick and Sulphate Attack: the Case of Moenjodaro, Pakistan", *Journal of Architectural Conservation*, No 13, Vol 1, 69-80

Goudie, A.S. (1977), "Sodium Sulphate Weathering and the Disintegration of Moenjodaro, Pakistan", *Earth Surface Processes*, vol 2, pp. 75-85

Hughes, R. (1995), *Moenjodaro Mission Report*, unpublished document, UNESCO, Paris

Hughes, R. (1996), "A Review of Works at the World Heritage Monument of Moenjodaro, Pakistan", in: M. Corfield, P. Hinton, and M. Pollard (Eds), *Preserving Archaeological Remains in Situ*, University of Bradford, Department of Archaeological Sciences, Bradford, pp. 26-30

Konishi, M.A. (1995), "Another Aspect for the Conservation of Mohenjo Daro: Development of the Site as a Regional Cultural Centre", *Indian Archaeological Studies*, 17, pp. 12-7

Jansen, M. (2003), "Moenjodaro, Pakistan. The Problems of Adobe and Brick Conservation", in: *Terra 2003, 9th International Conference on the Study and Conservation of Earthen Architecture*, Yazd pp. 309-318

Shaikh K.H. and Ashfaq S.M. (1981), *Moenjodaro: a 5000-year-old Legacy*, UNESCO, Paris

Spodek H. and Deris S. (eds) (1993), *Urban Form and Meaning in South Asia: The Shaping of Cities from Prehistoric to Precolonial Times*, Yale University Press

Teutonico, J.M (ed.) (1985), *International Architectural Conservation Course Laboratory Manual*, ICCROM, Rome

Various Authors (1987-1988), *Conservation of Structural Remains at Moenjodaro. Priority Estimation of Remaining Conservation Work*, Authority for the preservation of Moenjodaro, Department of Archaeology, Karachi

PLATES



Plate 1



Plate 2

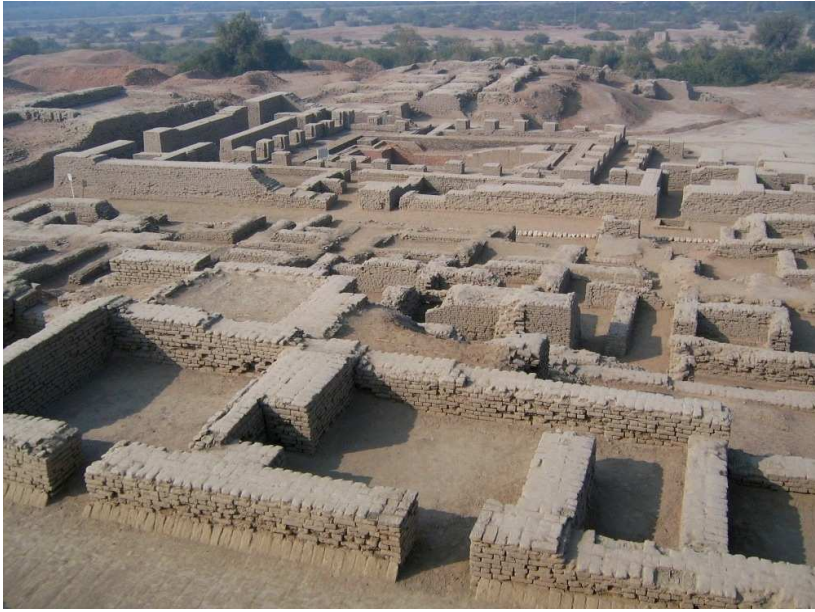


Plate 3



Plate 4



Plate 5



Plate 6



Plate 7



Plate 8

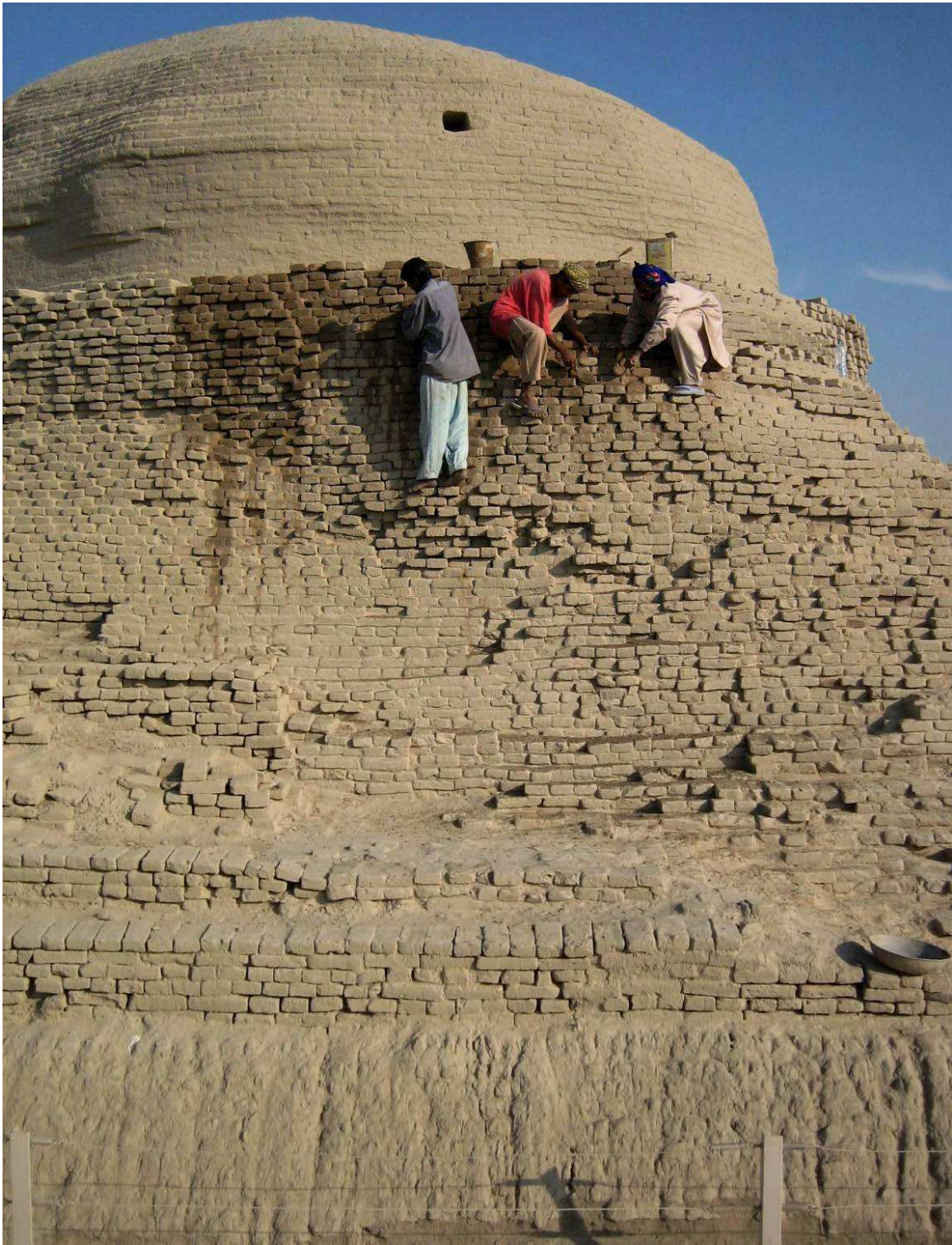


Plate 9



Plate 10



Plate 11

FIGURES

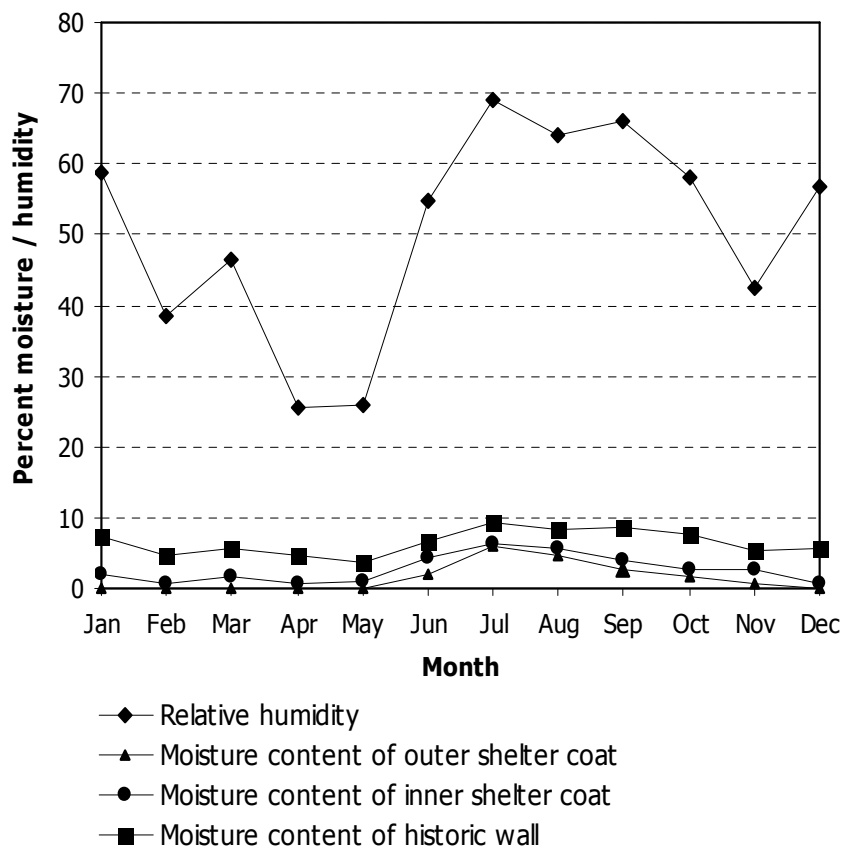


Figure 1

¹ The resulting report, *Moenjodaro and the Indus Civilization*, was published by Marshall in 1931.

² Mc Kay's excavation culminated with his study *Further Excavations at Moenjodaro*. Excavated areas were named with the initials of the archaeologists who worked in those portions: SD, L, W, DK-G, DK-B, DK-C, Moneer, VS, HR, UMP.

³ Bussagli (1981, 17) provides us with the reasons for the abandonment of the site: 'The civilization of the Indus valley declined because of a profound ecological change produced by its own expansion and activity. The colossal demand for fired brick and construction lumber brought about extensive deforestation in the entire basin. This in turn led to more frequent and destructive floods, a threat that increased with subsequent changes in the incline of the river bed, altered as well by slow coastal earth tremors.'

⁴ Bussagli (1981, 17) explains that some of the houses '...had more than one storey, had central courtyards on which the doors and windows opened. Entrance doors were placed on the lesser side streets. As a result, the principal streets, which were not wide, were lined by walls that were uninterrupted except by cross streets. There were no recesses for openings of any other kind.'

⁵ Cooper and Dawson (1989, 24) explain that 'Mud bricks appeared in the Indian subcontinent around 5000 BC. Settlements from that period have been found in Baluchistan (Pakistan). The new medium was drifting in with new people from the West. Mud brick was the principal material employed in the rise of the Indus culture (now generally known as Harappan civilization, from Harappa in Punjab, Pakistan, one of its major cities) which flourished from 2500 to 1750 BC, India's first civilization. This culture spread from the Indus valley as far as western Uttar Pradesh, and eastern Gujarat.'

⁶ Fired brick is employed with mud mortar. Cooper and Dawson (1989, 24) explain that 'The Harappan civilization was built on the technology for firing mud bricks. Unlike sun dried mud, fired clay withstands the prolonged direct contact with water inevitable for any settlement in an alluvial floodplain. The Indus valley, along which the civilization emerged, owes its fertility in part to annual flooding. Harappan towns are characterized by ramparts of burnt brick, raised as much for protection from monsoon inundation as from hostile armies. Permanent settlements built with this material allowed the inhabitants to exploit the

surrounding flood plain's agricultural potential, generating sufficient wealth to finance the subcontinent's earliest surviving monuments.'

⁷ The campus was built in the 1970s so as to host: WASIL laboratory, museum, guest house, employees accommodation, offices, storage rooms for conservation material, tourism office, police station, mosque, and post office. One chemist was appointed and trained at ICCROM (Rome), the Institute of Archaeology (University College of London), and the Istituto Centrale del Restauro (Rome).

⁸ Quarried near Dandh village Khaiwakh.

⁹ Quarried in Malook Shah, Noorshah.

¹⁰ The survey was carried out in 2005 by the Forest Department of Larkana in consultation with the University of Khairpur.

¹¹ The workshop was well attended by 24 participants from Moenjodaro and from institutions such as: Department of Archaeology sub regional office (Taxila), Southern Circle of Archaeology (Hyderabad), Directorate of Archaeology & Museums Peshwar (NWFP), Hamalyan Wild Life Foundation (Rohtas Fort), Department of Archaeology & Museums (Karachi), Sub Regional Office Shamas Abad Colony (Multan), Sindh Museum (Hyderabad), Department of Archaeology & Museums sub regional office (Quetta), Department of Archaeology & Museums (Karachi), National Museum of Pakistan (Karachi), Makli Hill Monuments (Thatta).